THESIS/
REPORT
BERNARDOS
[redacted]
C.L.D.A.

USE OF PONDEROSA PINE-GAMBEL OAK FORESTS BY BATS IN NORTHERN ARIZONA

00-JV-11221607-111
Bill Block

USE OF PONDEROSA PINE-GAMBEL OAK FORESTS BY BATS IN NORTHERN ARIZONA

Debra A. Bernardos, M.S. Candidate

Carol L. Chambers, Assistant Professor

Final Report

ABSTRACT-- Although Gambel oak (*Quercus gambelii*) represents less than 25% of the canopy cover in ponderosa pine-Gambel oak stands, it provides unique habitat for many vertebrates (e.g., cavity-nesting species, songbirds, and small mammals). Previous studies have indicated that Gambel oak may be an important roosting habitat for bats; however, no studies have determined specific characteristics of Gambel oak selected as roost trees. Hence, I conducted a bat habitat study in northern Arizona, summer 1999 and 2000. In 1999, I used mist nets over water to determine differences in species composition between ponderosa pine (*Pinus ponderosa*) and ponderosa pine-Gambel oak stands. At pine sites, I captured 429 bats representing 12 species. I captured 388 bats representing 14 species at pine-oak sites. All species captured at pine sites were also captured at pine-oak sites. Three species, southwestern myotis (*Myotis auriculus*), silver-haired bat (*Lasionycteris noctivagans*), and pallid bat (*Antrozous pallidus*), were captured more frequently in pine-oak sites than pine sites. During both years, I conducted a radio telemetry study locating the maternity roosts of lactating, female southwestern myotis within the pine-oak forest. I located 34 maternity roosts in Gambel oak trees (14 females) and 5 roosts in ponderosa pine snags (1 female). I also located 11 bachelor roosts of 4 male southwestern myotis. Gambel oak used as maternity roosts were large diameter, live trees containing internal cavities. Roost trees were taller than randomly-selected Gambel oaks and the forest immediately surrounding the roosts contained a higher density of large oak trees (diameter at root collar >26 cm). Large Gambel oaks are an important habitat component for several bat species in northern Arizona. The loss of these trees from fuelwood cutting and past forest management practices could negatively affect bat populations.

INTRODUCTION

Gambel oak is a sub-dominant and understory species in ponderosa pine forests in northern Arizona, representing less than 25% of the canopy cover. Gambel oak is a source of food, cover, den sites, nest sites, and foraging substrates for many wildlife species such as mule deer (*Odocoileus hemionus*), (Wright 1950, Patton 1968) Abert's squirrels (*Sciurus aberti*) (Keith 1965, Patton 1975), Merriam's wild turkeys (*Meleagris gallopavo merriami*) (Wakeling and Rogers 1995), cavity-nesting birds (Cunningham et al. 1980) and small mammals (Goodwin and Hungerford 1979). Rosenstock (1998) found that breeding bird diversity was higher in ponderosa pine-Gambel oak stands then in pure ponderosa pine stands. He believed that the higher diversity of birds might be linked to the fact that Gambel oak provided more cavities, higher quality or preferred foraging substrates for foliage and bark gleaning birds, and a greater insect biomass than ponderosa pine.

However, little information is known about the habitat use of Gambel oak by forest- dwelling bats. In northern Arizona, Morell et al. (1999) compared bat communities between a ponderosa pine and a ponderosa pine-Gambel oak forest, but ponderosa pine sites were at higher elevations than ponderosa pine-Gambel oak sites. Two studies documented the use of Gambel oak as a roost tree by 3 bat species, southwestern myotis, long-eared myotis (*Myotis evotis*) (Rabe et al 1998), and big brown bat (*Eptesicus fuscus)* (Lutch 1996). However, sample sizes were small (1 or 2 bats in each study) and neither study described the characteristics of the Gambel oak trees used.

Bats use habitats for foraging, the procurement of water, and roosting. Roosts play a vital role in the lives of bats, providing sites for mating, hibernating, rearing of young, social interactions, digestion of food and protection from weather and predators (Kunz 1982). The

types and locations of roost sites chosen by bats and also the availability and physical capacity of roosts have a strong influence on survival and fitness (Kunz 1982, Vonhof and Barclay 1996). Roost sites are of particular importance to reproductive females. Reproductive females often form maternity colonies where many females congregate to raise their young. The selection of warm microclimates in roosts during the maternity period has been found to promote the optimum growth of newborn bats (McNab 1982).

The purpose of this study was twofold. My first objective was to describe and compare bat communities in ponderosa pine and ponderosa pine-Gambel oak forests at similar elevations. My second objective was to locate and describe maternity roosts of southwestern myotis. A bat species whose daytime and maternity roosts were unknown (Arizona Game and Fish Department 1991). The Western Bat Working Group (1998) listed southwestern myotis as a species of medium concern in what they classify as the Colorado Plateau semi-desert and Arizona-New Mexico mountains and semi-desert ecoregion. The designation of a species of medium concern, "indicates a level of concern that should warrant closer evaluation, more research, and conservation actions of both the species and possible threats". I wanted to determine if southwestern myotis selected maternity or bachelor roosts in Gambel oak trees.

METHODS

Study Areas

In the summer of 1999 and 2000, I captured bats at 2 study areas in the Coconino National Forest in northern Arizona (Figure 1). The first location (hereafter, pine site) was located 12 km northwest of Flagstaff (35°15'N, 111°45'W). Elevations ranged from 2,198 to 2,353 m. The pine site was a ponderosa pine-grassland community dominated by ponderosa pine, Arizona fescue *(Festuca arizona)*, and mountain muhly (*Muhlenbergia montana*). The second location,

(hereafter, pine-oak Site) was located 25 km south of Flagstaff (35°N, 111°37'30"W) with elevations ranging from 2,042 to 2,327 m. The pine-oak site was dominated by a ponderosa pine-Gambel oak (*Quercus gambelii*) community with an understory of New Mexican locust (*Robinia neomexicana*), alligator juniper (*Juniperus deppeana*) and Utah juniper (*Juniperus osteosperma).*

Mean temperatures and precipitation (°C-cm) for the Flagstaff area for June, July and August of 1999 and 2000 were 14-2.4, 18-8.3, 17-6.2 and 17-2.8, 19-.73, 18-7.2, respectively (Western Regional Climate Center 2001).

Bat Surveys

Between June 8 and July 16, 1999, I capture bats over 20 nights at 25 man-made earthen water tanks (Pine Site, n = 12, Pine-oak Site n = 13) to compare bat community differences between the two habitat types (Table 1). Mist nets were set up across the open water in a Z-, W-, or V- configuration. Length of net used varied with the size of each water body. Nets were opened at dusk (between 19:40-20:00) and remained open for at least 2 hours or until midnight depending on bat activity. All captured bats were identified to species, gender, and age. I determined age (juvenile or adult) by looking for the presence of cartilaginous epiphyseal plates in the phalanges (Anthony 1982). I measured weight with a Pesola spring scale (to the nearest 0.2 g) and forearm length (to the nearest 0.1 mm) to aid in the identification of some species. I also assessed reproductive condition. The abdomens of females were palpated for evidence of pregnancy, and mammary glands were checked for evidence of lactation. I examined males to determine if they were in a scrotal or non-scrotal condition. Bats were released usually within ≤15 minutes of capture. In 2000, I mist netted 17 water bodies in the ponderosa pine-Gambel

oak forest to capture lactating southwestern myotis females and males for attachment of radio transmitters. I recorded the same biological information as I did in 1999.

Radio Telemetry

In the summer of 1999 and 2000, I conducted a radio-telemetry maternity roost study within the pine-oak study area. I attached radio-transmitters between the scapula of 18 southwestern myotis females with non-toxic latex-based glue. All radio-tagged females were lactating and weighed greater than 7 g. On average, transmitter mass was ≤7% of the mass of the bat, which is only slightly over the 5% rule (Aldridge and Brigham 1988). Transmitters were also placed on 4 male southwestern myotis (≥7 g) to describe their day roosts and compare with females. All bats were released ≤25 minutes once the glue had dried.

I located day roosts using radio telemetry. I located bat roosts daily until the transmitter fell off or ceased to produce a signal. Exit counts were performed when time, personnel, and weather permitted to check for the occupancy of the radio-tagged bat and determine if other bats were present.

Vegetation Sampling

To determine roost tree and forest characteristics selected by southwestern myotis lactating females, I compared roost trees to randomly-selected ("random") trees. I selected a random tree approximately 200 m from the roost tree in a randomly selected compass direction (Brigham et al. 1997). I defined random trees as either Gambel oak trees ≥26 cm diameter at root collar and ≥3 m in height within the decay class range of 2 to 6 (Table 2) or dead ponderosa pine trees ≥30.5 cm diameter at breast height and ≥3 m in height (Rabe et al. 1998). I chose the Gambel oak criteria because Gambel oak roosts found in my study were ≥ these sizes.

I measured the characteristics of roost sites and random sites at two spatial scales: (1) the individual roost or random tree and (2) the forest microhabitat (0.1ha) surrounding the roost or random tree (Rabe et al. 1998). For characteristics of the roost tree, I classified the roost site as a natural cavity, excavated cavity, or loose bark. I measured diameter at root collar (drc) for Gambel oak trees and diameter at breast height (dbh) for pine snags and determined tree height, cavity height or loose bark height, slope of cavity entrance or loose bark, and slope of the tree. I measured the aspect of the roost entrance or loose bark and the aspect of the roost or random tree on the slope. I classified the condition of the roost and random tree (Tables 2 and 3) and estimated percent bark remaining on decaying trees. Finally, I determined the distance of the tree from open water (m). To measure the characteristics of the forest microhabitat surrounding the roost tree, I established a 0.1ha (17.8 meter radius) circular plot around each roost and random tree (Vonhof and Barclay 1996, Brigham et al. 1997). In each plot, I identified all trees to species and measured the dbh or drc of each tree ≥5 cm. I determined percent canopy closure with a visual estimate (crude ocular). I calculated basal area and density of ponderosa pine, Gambel oak, and potential roost Gambel oak (≥26 cm drc).

To determine if females were selecting roost tree species in proportion to potential roost tree species found in the area surrounding the roosts, I placed either 4 100-m transects or 2 200- m transects (depending on the proximity of other roosts) in random directions at each roost site. On each transect at 20-m intervals, we counted the number of potential roost Gambel oak trees and ponderosa pine snags that could be visually located from that observation station. Gambel oak trees ≥26 cm drc, ≥3 m height, and with visible cavities or in decay classes 2 to 6 and ponderosa pine snags ≥30.5cm dbh, ≥3 m height, and in decay classes 2 to 7 (Rabe et al. 1998) were defined as available for southwestern myotis roosting. All trees were counted only once even if

seen from more than 1 observation point. A distance and bearing to the observed trees was measured at each station.

Statistical Analyses

Bat community comparison

I compared number of bats of each species captured at pine vs. pine-oak sites. I pooled gender for each species. Since area of net used and time spent at each water source differed among sites, I calculated an index of abundance by weighting the number of captures by netting effort (Rabe 1999). Netting effort was calculated as (hours spent netting in the type of forest x area of net (m^2) used in each type of forest)/100 (Rabe 1999). Using my index of abundance, I calculated percent capture for each bat species and made comparisons between both forest types.

Maternity Roost Selection

I used multiple logistic regression (Hosmer and Lemeshow 1989) to determine which characteristics of trees and forest microhabitat best discriminated between Gambel oak roost and random trees. The number of parameters allowed per model was limited by roost sample size (1 parameter for every 10 roosts). I set three criteria for developing these models. I wanted simple models that made biological sense, and could be used by managers to identify possible areas of roosting habitat. I based my models on roost characteristics found to be significant in past bat roost studies. Roost trees tended to be taller in height, have a larger diameter at breast height, and are closer to other available trees (Campbell et al. 1996, Sasse and Pekins 1996, Vonhof and Barclay 1996, Brigham et al. 1997, Betts 1998, Rabe et al. 1998).

I used Akaike's Information Criterion (AIC) for model selection and ranked models using Δ AIC (Burnham and Anderson 1998). I calculated AIC values for each model using the formula: -2 Log Likelihood + 2k, where k equals the number of parameters in the model plus a constant. I

calculated Δ AIC by subtracting the lowest AIC value from each of the other AIC values. I accepted models with Δ AIC <4 (Burnham and Anderson 1998). Models were validated using jackknife procedures. For descriptive statistics, all means are followed by ± 0.1 standard error with the range in parentheses.

For maternity roosts, I used DISTANCE (Laake et al. 1998) to model potential roost tree densities in the areas surrounding roost trees. I used DISTANCE to calculate relative abundance of potential roost Gambel oak trees and ponderosa pine snags. I selected the model with the lowest Δ AIC and highest Chi-square value. To determine if female southwestern myotis selected roost trees in proportion to available, I used a Chi-square test of homogeneity (Ott 1992) to compare the proportion of tree species used to the proportion of potential roost tree species present. A Chi-square goodness of fit test was inappropriate, since I estimated the abundance of available trees (Thomas and Taylor 1990). Chi-square values were considered only if the expected values were ≥5 (Cochran 1954). For all statistical tests, I used $\alpha = 0.05$ as my level of significance.

RESULTS

Bat community comparison

I captured 429 bats representing 12 species in the ponderosa pine forest (Table 4). I captured 388 bats representing 14 species in the ponderosa pine-Gambel oak forest. All species captured at pine sites were also captured at pine-oak sites. Netting effort was 1186 hrm^2 in the pine-oak forest and 1176 hrm^2 in the pine forest. The long-legged myotis (*Myotis volans*), Mexican free-tailed bat (*Tadarida brasiliensis*), and the hoary bat (*Lasiurus cinereus*) had a higher percent capture in pine sites than in pine-oak sites (Table 4). Southwestern myotis, pallid bat, and silver-haired bat were captured in higher percentages in pine-oak than in pine sites. The long-eared

myotis, big brown bat, and Arizona myotis (*Myotis occultus*) were captured equally in both types of forest. The big brown bat and Arizona myotis had the highest number of captures over both sites.

Roost selection

I tracked 15 of 18 females (1 transmitter failed and 2 of the radio-tagged females could not be located due to signal bounce from surrounding canyon rock walls). I tracked all 4 males. I located 39 maternity roosts. Thirty-four of the maternity roosts (14 females) were located in Gambel oak trees; 5 maternity roosts (1 female) were located in ponderosa pine snags. I also tracked 4 female transmitter signals to 4 live ponderosa pine trees, which were not considered as day roosts. Primary roosts (first roosts used) were located 1335 ± 205. (254 - 3381) m from the water body of capture. Female southwestern myotis used 3.0 ± 0.4 (1 - 6) roosts, remaining at each roost 2.0 ± 0.2 (1 - 6) days. The mean distance between roosts for females was 231 ± 41 (20 - 1110) m.

Eighty-five percent of Gambel oak roosts were live trees with some decay present. Five oak roosts were snags (decay class 3 or 4). Gambel oak roosts were large, tall trees with a high percentage of bark remaining (Table 5). Oak maternity roosts were found mainly on southwestern-to western-facing slopes. Southwestern myotis used natural cavities (n = 10) caused by branch scars and 1 excavated cavity. Only once were females found using loose bark. Mean cavity entrance height was 6.2 ± 1.0 (1.7 -12.5) m. The forest microhabitat surrounding the roost tree (0.1 ha) had a mean percent canopy closure of 82 ± 2 (28 -82). I performed 11 exit counts on oak roosts. Number of bats exiting ranging from 0 to 43.

One female southwestern myotis used 5 ponderosa pine snags with a decay class ranging from 2 to 4. Pine snag roosts had a mean dbh and height of 82.5 ± 5 (71.7 - 95.5) cm and 25.4 ±

1 (23.4 - 27.4) m, respectively. Percent bark varied ranging from 1 to 95%. Roosts were found on steep, western facing slopes. The area surrounding the roost had a mean percent canopy closure of 61 ± 5 (47 - 72)%. Mean basal area was 50 ± 7 (29 - 66) m^2/ha for pines and 11 ± 3 (5 - 23) m^2/ha for oaks. Ponderosa pine density was 986 ± 105 (830 - 1390) stems/ha and oak density was 450 ± 146 (150) - 990) stems/ha.

Male roosts were located in 8 Gambel oak trees, 1 ponderosa pine snag, 1 ponderosa pine stump, and 1 fallen pine snag. Bachelor roosts were located 1291 ± 389 (388 - 1947) m away from the water body of capture. Males used from 1 to 6 roosts and stayed at each roost for 1 to 4 days. Two males each returned to 1 previously used roost during the time they were tracked. The mean distance between roosts was 379 ± 66 (50 - 562) m. Gambel oak trees used by males were live trees, decay class 2 (only 1 snag, decay class 5, was used) with a mean drc of 30.1 ± 6.7 (11.5 - 65.3) cm and a height of 8.5 ± 2.3 (3 - 18.8) m. The pine snag roost had a dbh of 75 cm and a height of 8.8 m. One male was located in the upright branch of a fallen ponderosa pine snag. The diameter of the branch was 16.4 cm and the branch was 3.3 m high. Another male was located behind the bark of a 1-m high, 26 cm ponderosa pine stump.

The model that best described female southwestern myotis habitat use used tree height and density of potential roost trees (oak trees ≥26 cm drc in the 0.1ha plot), surpassed the other three models when discriminating between Gambel oak roost trees and random oak trees. This model accurately classified 75% of the roosts and 69% of the random trees. Gambel oak trees were taller than randomly-selected trees and were surrounded by a higher density of potential roost Gambel oak trees (Table 6) were likely to be used by southwestern myotis females. Basal area (m^2/ha) of Gambel oak trees was higher in areas surrounding roosts than random trees. I did not detect a difference between diameters of roost and randomly-selected trees.

Density and abundance estimates for available ponderosa pine snags and Gambel oak trees produced by DISTANCE were 2 stems/ha (890 stems) and 21 stems/ha (8824 stems), respectively. The chi-square test of homogeneity ($\chi^2 = 0.817$, $P = 0.336$) indicated that for all females ($n = 15$), southwestern myotis are selecting trees species in proportion to tree species available in the roosting areas.

DISCUSSION

Bat community comparison

Bat communities were similar in species richness between ponderosa pine and ponderosa pine-Gambel oak forests, although the relative abundance of some bat species differed. Morrell et al. (1999) found similar results across a broader range of elevations (2,262 to 2,621 m ponderosa pine sites and 2,018 to 2,276 m ponderosa pine-Gambel oak sites). The elevation differences did not appear to affect species composition. Likewise, relative bat abundance did not appear to change during the 4-year period between my study and Morrell et al.'s (1999).

Maternity Roost selection

Southwestern myotis females used Gambel oak trees as maternity roosts with the exception of one southwestern myotis that used pine snags. Roosting behaviors differed between bats using Gambel oak and the bat that used ponderosa pine snags. Bats using Gambel oak stayed on average 2 days at a particular roost, whereas the pine snag female moved every day. This may be related to the ephemeral nature or quickly changing microclimate of loose bark on snags (Rabe et al. 1998). Cavities within Gambel oak may produce a more long-term stable environment. Similarly, the female using ponderosa pine snags, although identified as lactating at the time of capture, may have lost her offspring, negating the need to conserve energy and allowing her to move daily.

Males also roosted more often in Gambel oak trees, but appeared to be more opportunistic in their choice of roosts. Males roosted alone in small cracks or in cavities that were large enough for only 1 bat. Roosts that provided warm microclimates are likely to be less important to males because they likely conserved energy by entering torpor (Betts 1998).

Four southwestern myotis females were tracked to 4 live ponderosa pine trees (26 to 30 cm dbh) in close proximity to the water source of capture (<200 m). I inspected the trees with binoculars and they appeared to possess all their bark and did not have cracks or cavities. One tree was climbed and the transmitter was found stuck to the bole of the tree. I did not observe bats leaving these trees when I performed exit counts and the radio signals also did not leave the tree and remained there each day until the transmitter died. I did not include these trees in analysis because I felt that they were not day roosts. I hypothesize that these trees are night roosts (Kunz 1982), were used as resting places to groom, or that the transmitters fell off and landed there during flight.

Since I could not monitor randomly-selected or potential roost trees for the entire field season, I could not ensure that bats at some point did not use these trees during the year or in previous years. Therefore, I do not make the assumption that the random trees were unused by bats. Instead, I consider them structurally available trees that the bats in my study did not use during the time I monitored them.

Previous studies of bat roosts have shown that roost trees tend to be taller, have larger diameter and were closer to available trees (Campbell et al. 1996, Sasse and Pekins 1996, Vonhof and Barclay 1996, Brigham et al. 1997, Betts 1998, Rabe et al. 1998). One of the 4 models I used further supported these findings and met model selection criteria (Δ AIC <4). Gambel oak roosts were taller than random trees and had a higher density of potential roost

Gambel oak trees surrounding the roost tree. Only this model, Height + Potential roost Gambel oak trees/ha containing both a tree and a forest microhabitat characteristic, could be used to identify potential roost trees and or roosting habitat.

Southwestern myotis females were selecting roost tree species (Gambel oak) in proportion to potential roost tree species available in the forest area surrounding roosts. I believe bats are using Gambel oak because it was more abundant than pine snags and was easier to procure. Although I cannot clearly show selection of Gambel oak by southwestern myotis females, the abundance of potential roost trees, however, did not mean that these trees are suitable roosts (Brigham and Fenton 1986). I used only external characteristics to determine if a tree could be considered an available potential roost tree. Availability is probably based on many factors, including microclimate, occupancy by other invertebrates and vertebrates, and vulnerability to or presence of predators. Further, if females are not selecting tree species on the individual tree level they may be selecting Gambel oak on different scales such as on the scale of the cavity (size or shape) or on the landscape scale.

Vonhof and Barclay (1996) believed some bats selected tree species that provided suitable conditions for cavity formation and that the tree species selected was a function of the tree's decay characteristics. Gambel oak can naturally produce many cavities of various sizes within the limbs and bole of the tree. Cavities are caused most often by heart rot fungus (*Polyporus dryophilus*) which is common in Arizona (Kruse 1992). Cavities are typically found in mature oaks, but cavities can also form in smaller oaks as well.

Female southwestern myotis used tall, large diameter, live Gambel oak trees with a high percentage of bark remaining, but with some decay. Bats were found using natural cavities whose entrances were created by decaying branch scars. Female southwestern myotis used large

Gambel oak trees, but may have selected these trees because they provided suitable cavities. Size of a tree may limit cavity size and in turn limit the size of a bat maternity colony (Vonhof and Barclay 1996). Large, live trees with some decay (decay class 2), but with a large percentage of bark remaining would have more solid wood present and thus have greater insulating value (Betts 1998). Cavities in taller trees may receive more solar radiation during part of the day. These factors (size of cavity, amount of solar radiation received, and the insulating value of the tree) could affect thermoregulatory costs of females and their offspring. Female southwestern myotis would therefore benefit by using large, live Gambel oak trees.

Pierson (1998) stated that when examining the habitat requirements of forest bats, the abundance and distribution of potential roost trees might be as important as the roost tree. Southwestern myotis females were found using Gambel oak trees surrounded by higher densities of potential roost trees in close proximity (0.1ha plot). I found higher densities of potential roost Gambel oak trees when compared to ponderosa pine snags in a larger area surrounding roost trees (transects). Also, bats in this study frequently switched roosts, but used multiple trees within in a close proximity of other roosts, appearing loyal to a particular area.

Roost switching is common in tree roosting species (Taylor and Savva 1988, Kurta et al. 1996, Ormsbee 1996, Sasse and Pekins 1996, Vonhof and Barclay 1996, Brigham et al. 1997, and Rabe et al. 1998). Roost switching is believed to occur in response to disturbance, predator avoidance, microclimate changes, and ectoparasite avoidance (Lewis 1995). However, roost switching has high-energy costs due to energy lost from moving young (Brigham and Fenton 1986, Lewis 1995). The presence of many potential roost trees in a small area may reduce energy cost since search and travel time would be lowered, benefiting from site familiarity (Vonhof and Barclay 1996, Lewis 1995).

. Roost locations were grouped over the study area with transmittered bats roosting together at times or in the same areas. On 1 occasion, 2 bats captured at different tanks (4 km apart) on different nights were found roosting together in an area halfway between both tanks. The 2 females roosted together the first day, roosted together in a different tree on the second day, and roosted in separate trees on subsequent days, but on the same hillside. I observed this with 4 other bats in my study.

From potential roost tree density data and observed bat behavior, southwestern myotis females appeared to be selecting patches of Gambel oak trees. Likewise, they seemed to be using tall, large live Gambel oak trees that provided them with suitable cavities. However, I focused on a small scale (roost tree level). Investigation of cavity microclimates and distribution of available roost tree patches over the landscape are beyond the scope of this study, but warrant further investigation. Possible future research questions might be: Do females select patches of potential roost Gambel oak in proportion to availability across the landscape? Are the same Gambel oak patches used annually? How do microclimates of Gambel oak cavities compare to other roosting structures?

MANAGEMENT IMPLICATIONS

Past management of Gambel oak has focused on control and removal of this species, since it was considered a pest by the timber industry and people who graze livestock (Harper et al 1985, Harrington 1985, Clary and Tiedemann.1992). The importance of Gambel oak as a resource for wildlife has been discussed since the late 1940's. Early management recommendations for Gambel oak suggested only leaving oaks less than 38 cm dbh with more than 80% live tops as a reasonable compromise to preserve wildlife habitat (McCulloch et al. 1965). Later management

recommendations added the need to preserve old, decadent oaks that showed sign of den use (Reynolds et al. 1970, Neff et al. 1979).

Large Gambel oak trees should be retained to manage for the habitat requirements of southwestern myotis, but also for other vertebrate species that may benefit from cavities. Large Gambel oak trees can be lost by fire, windthrow, branch and bole breakage that exposes the cavities, or fuelwood cutting. Fuelwood cutting is of particular concern since Gambel oak is a popular fuelwood that possesses superior heat-producing qualities and is quite accessible to populated areas (Wagstaff 1984).

Although the Coconino National Forest in northern Arizona has regulations against cutting standing Gambel oak trees, cutting of trees frequently occurs. Fuelwood cutters tend to target mature trees; often abandoning cut trees if they are hollow (Kruse 1992, and personal observation). I found signs of Gambel oak harvest near all the roosting areas I located. Gambel oak has a very slow volume growth rate of about 2% each year (Barger and Ffolliott 1972). Therefore, replacement of large trees will occur slowly. This replacement rate of large Gambel oak may be too slow for maintaining southwestern myotis roost habitat.

I recommend that forest managers consider Gambel oak/wildlife relationships when proposing prescribed burns, harvesting, or restoration treatments. Destruction of known bat roosts or habitat should be avoided. I suggest that large oak trees, > 30 cm drc need to be protected whether they show signs of wildlife use or not. However, all Gambel oak growth forms, brushy, sapling pole, mature stages, should be considered when managing for wildlife. These growth forms are a source of food, cover, den sites, nest sites, and foraging substrates for many wildlife species. Likewise, management and protection of the smaller size classes will promote replacement of large, Gambel oaks in the future.

LITERATURE CITED

Aldridge, H.D. and R.M. Brigham. 1988. Load carrying and maneuverability in an insectivorous bat: a test of the 5% "rule" of radio telemetry. Journal of Mammalogy. 69:379 -382.

Anthony, E.L.P. 1982. Age determination in bats. pages 47 -58 In T.H. Kunz, editor. Ecology of bats. Plenum Press, New York, NY, USA.

Arizona Game and Fish Department. 1991. Bats of Arizona. Prepared by the Education Branch of the Arizona Game and Fish Department.

Barbour, R. W., and W. H. Davis. 1969. Bats of America. Lexington: University Press of Kentucky.

Barclay, R. M. R. and R. M. Brigham, editorss. 1996. Bats and Forests Symposium, October 19-21, 1995. Victoria, British Columbia. Working Paper 23/1996. Research Branch, Ministry of Forests, Victoria.

Barger, R. L. and P. F. Ffolliott. 1972 .The Physical characteristics and utilization of major woodland tree species in Arizona. Research Paper RM- 3 USDA Forest Service. Rocky Mountain Forest and Range Experiment. Station., Fort Collins, CO.

Betts, B. J. 1998. Roosts used by maternity colonies of silver-haired bats in northeastern Oregon. Journal of Mammalogy, 79:643-650.

Brigham, R. M. and M. B. Fenton. 1986. The influence of roost closure on the roosting and foraging behaviour of Eptesicus fuscus (Chiroptera: Vespertilionidae). Canadian Journal of Zoology. 64:1128-1113.

Brigham, R. M., Vonhof, M. J. Barclay, R. M. R. and Gwilliam, J. C. 1997. Roosting behavior and roost-site preferences of forest-dwelling California bats (*Myotis californicus*). Journal of Mammalogy 78:1231- 1239.

Burnham, K. P. and D. R. Anderson. 1998. Model selection and inference: a practical information- theoretic approach. Springer, New York, New York, USA.

Campbell, L. A., J. G. Hallett, and M. A. Oconnell. 1996. Conservation of bats in managed forests: use of roosts by *Lasionycteris noctivagans*. Journal of Mammalogy 77:976-84.

Cochran, W. G. 1954. Some methods for strengthening the common χ^2 test. Biometrics 10:417-451.

Clary, W.P. and A.R. Tiedemann. 1992. Ecology and values of Gambel oak woodlands. In Ecology and management of oak and associated woodlands: perspectives in the southwestern U.S. and northern Mexico. USDA Forest Service, GTR RM-218.

Cunningham, J.B. R. P. Balda, and W.S. Gaud,. 1980. Selection and use of snags by cavity-nesting birds in ponderosa pine forest. USDA Forest Service. Research Paper RM-222, Fort Collins, Co.

Goodwin, J.G. Jr. and C. R. Hungerford. 1979. Rodent population densities and food habits in Arizona ponderosa pine forests. USDA Forest. Service. Research Paper RM-214, 12p. Rocky Mt. For. And Range Exp. Stn., Fort Collins, CO.

Harper, K.T., F.J. Wagstaff, and L.M. Kunzler. 1985. Biology and management of the Gambel oak vegetative type: a literature review. USDA Forest Service GTR INT-179.

Harrington, M.G. 1985. The effects of spring, summer, and fall burning in a southwestern ponderosa pine stand. Forest Science 31:156-163.

Hosmer, D. W. and S. Lemeshow. 1989. Applied logistic regression. John Wiley & Sons, New York, New York, USA.

Keith, J.O. 1965. The Abert squirrel and its dependence on ponderosa pine. Ecology 46:150-163.

Kruse, W.H. 1992. Quantifying wildlife habitats within Gambel oak/forest/woodland vegetation associations in Arizona. Ecology and Management of Oak and Associated Woodlands.: Perspectives in the Southwestern United States and Northern Mexico. A symposium, Sierra Vista, AZ, April 27-30.

Kunz, T. H. 1982. Roosting ecology of bats. Pages 1-55 In T. H. Kunz, editor. Ecology of bats. Plenum Press, New York, NY, USA.

Kurta, A., K. J. Williams, and R. Mies. 1996. Ecological, behavioral, and thermal observations of a peripheral population of Indiana bats (*Myotis sodalis*). In Barclay, R.M.R. and R.M. Brigham, eds. Bats and Forests Symposium, October 19-21, 1995. Victoria, British Columbia. Working Paper 23/1996. Research Branch, Ministry of Forests, Victoria.

Lewis, S. E. 1995. Roost fidelity in bats: a review. Journal of Mammalogy 76:481-496.

Lutch, D. J. 1996. Maternity roost characteristics and habitat selection of three forest-dwelling bat species in Arizona. M.S. Thesis. Arizona State University. Phoenix. 85p.

McCulloch, C. Y. O. C. Wallmo, and P. F Ffolliott,. 1965. Acorn yield in northern Arizona. USDA Forest Service. Rocky Mountain Forest and Range Experiment. Station., Fort Collins, CO. Research Note.. RM-48,2p

McNab, B. K. 1982. Evolutionary alternatives in the physiological ecology of bats. pp. 151-200. in T.H. Kunz, editor. Ecology of bats. Plenum Press, New York, NY, USA.

Morrell, T. E., M. J. Rabe, J. C. Devos, H. Green, and C. R. Miller. 1999. Bats captured in two ponderosa pine habitats in north-central Arizona. The Southwestern Naturalist 44:501 - 506.

Neff, D.J., C. Y. McCulloh, D. E. Brown, C. H. Lowe, J. F Barstad. 1979. Forest, Range, and Watershed management for enhancement of wildlife habitat in Arizona. Sp. Rep. #7 AZ Game and Fish Dept. Phoenix, AZ.

Ormsbee, P. 1996. Selection of day roosts by female long-legged myotis (*Myotis volans*) in forests of the central Oregon Cascades. M.S. Thesis. Oregon State University, Corvallis.

Ott, L. 1992. An introduction to statistical methods and data analysis. Duxbury Press. Belmont, California.

Patton, D.R. 1968. Deer and elk use of a ponderosa pine forest in Arizona before and after timber harvest. U.S. Forest Serv. Res. Note RM-139, 7p. Rocky Mountain Forest And Range Exp. Sta., Fort Collins, Colo.

Patton, D.R. 1975. Abert squirrel cover requirements in southwestern ponderosa pine. USDA Forest Service. Rocky Mountain. Forest and Range Experiment. Station., Fort Collins, CO Research Paper RM-145, 12p

Pierson, E.D. 1998. Tall Trees, Deep Holes, and Scarred Landscapes: Conservation Biology of North American Bats. In Kunz, T.H. and Racey, P.A. editors. Bat Biology and Conservation. Smithsonian Institution Press, Washington.

Rabe, M. J. 1999. Bat use in pinyon-juniper woodland and grassland habitats in northern Arizona. M.S. Thesis. Northern Arizona University, Flagstaff.

Rabe, M. J., T. E. Morrell, H. Green, J. C. Devos Jr., and C. R. Miller. 1998. Characteristics of ponderosa pine snag roosts used by reproductive bats in northern Arizona. Journal of Wildlife Management 62:612-21.

Reynolds, H.G., Clary, W.P. Ffolliott, P.F. 1970. Gambel oak for southwestern wildlife. Journal of Forestry. 68(9):545-547.

Rosenstock, S. S. 1998. Influence of Gambel oak on breeding birds in ponderosa pine forests of northern Arizona. The Condor. 100:484 -492

Sasse, D. B. and P. J. Pekins, 1996. Summer roosting ecology of northern long-eared bats (*Myotis septentrionalis*) in the White Mountain National Forest. In Barclay, R.M.R. and R.M. Brigham, editors. Bats and Forests Symposium, October 19-21, 1995. Victoria, British Columbia. Working Paper 23/1996. Research Branch, Ministry of Forests, Victoria.

Taylor, R.J. And N.M. Savva. 1988. Use of roost sites by four species of bats in state forest in south-eastern Tasmania. Australian Wildlife Research 15:637-645.

Thomas, L., J. L. Laake, J. F. Derry, S. T Buckland, D. L Borchers, D. R. Anderson, K. P. Burnham, S. Strindberg, S. L. Hedley, M. L. Burt, F. Marques, J. H.Pollard and R. M. Fewster. 1998. DISTANCE 3.5. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK.

Thomas, D. L. and E. J. Taylor. 1990. Study design and tests for comparing use and availability. Journal of Wildlife Management 54:322-330.

Vonhof, M. J. and R. M. R. Barclay. 1996. Roost site selection and roosting ecology of forest dwelling bats in southern British Columbia. Canadian Journal of Zoology 74:1797-805.

Wakeling, B.F. and Rogers, T.D. 1995. Winter habitat relationships of Merriam's turkeys. Arizona Game and Fish Department. Technical Report. 16. Phoenix, AZ.

Wagstaff, F.J. 1984. Economic considerations in use and management of Gambel oak for fuelwood. GTR INT-165. Ogden, UT: USDA. Forest Service. Intermountain Range Experiment Station.

Western Regional Climate Center. 2001. Monthly Average Temperature and Precipitation, Flagstaff WSO AP, Arizona. http://www.wrcc.dri.edu/. Accessed on February 8, 2001.

Wright, J. T. 1950. North Kaibab deer-livestock forage relationship study. Arizona Game & Fish Communication., mimeo. 223p.

Table 1. Site name, Location (Universal Transmercader Coordinates), number of visits, length of net used at each site, hours spent mist netting, number of bats captured, and species abbreviations of bats captured at water sources for a bat communtiy comparison study in northern Arizona, Coconino National Forest, between June - July 1999. Species abbreviations: *Antrozous pallidus* (Ap), *Eptesicus fuscus* (Ef), *Idionycteris phyllotis* (Ip), *Lasionycteris noctivagans* (Ln), *Lasiurus cinereus* (Lc), *Myotis auriculus* (Ma), *M. californicus* (Mca), *M. ciliolabrum* (Mci), *M. evotis* (Me), *M. occultus* (Mo), *M. thysanodes* (Mt), *M. volans* (Mv), *M. yumanensis* (My), *Tadarida brasiliensis* (Tb).

Tank Name	UTM E	UTM N	# of visits	Length (m) of nets (range)	Hours netted (range)	# of captures	Species Captured
Pine-oak Site							
Frank Tank	12 451611	3856518	2	18	2.6 - 2.7	14	Ap, Ef, Ln, Mo, Mv, My
Corner Tank	12 443824	38760	1	18	3.2	8	Ln, Ef, Ma, Mo, Mt,
Mud Spring Tank	12 450319	3868494	2	6 - 18	3.5 - 3.6	90	Ef, Lc, Ln, Ma, Mci, Me, Mo, Mt, Mv
Coulter Tank	12 442109	3873573	2	12 - 18	3.6 - 2.8	81	Ap, Ef, Lc, Ln, Ma, Mci, Me, Mo, Mt, Mv
Kelly Tank	12 452792	385725	2	18	1 - 3.2	20	Ef, Ip, Ln, Ma, Me, Mo, Mv, My
Kelly 235 Tank	12 440330	3878728	2	12 - 18	3.3 - 3.7	42	Ap, Ef, Lc, Ln, Ma, Mci , Me, Mo, Mt, Tb
Pen Tank	12 453355	3862712	2	9 - 18	2.4 - 3.2	27	Ef, Ip, Ln, Me, Mo, Mt, Mv,
T-six Tank	12 448460	3861080	1	18	2.6	4	Ap, Mt, Mv
Jones Tank	12 449213	3862674	2	12 - 18	2.8 - 3.7	45	Ap, Ef, Lc, Ma, Mca, Mci, Me, Mo, Mt, Mv
Scooter Tank	12 445700	3861420	1	12 - 18	3.6	12	Ap, Ef, Ln, Ma, Mo,
Rock Dike Tank	12 452144	3867093	1	12 - 18	3.25	15	Ef, Me, Mo, Mt, Mv, Tb
Oak Grove Tank	12 449160	3856020	1	18	3.8	21	Ap, Ef, Ip, Me, Mo, Mt
Half Pint Tank	12 442787	3875573	1	12 - 18	2.9	10	Ef, Ln, Ma, Mo, Mt,
Pine Site							
South Wing Tank	12 427720	3902020	2	12 - 18	3.3 - 3.8	43	Ef, Ma, Me, Mo, Mt, Mv
Johnson Tank	12 428888	3901021	1	12 - 18	3	10	Ef, Ln, Me, Mo, Mt, Mv
171E Tank	12 422635	3904770	1	12 - 18	3	12	Me, Mo, Mv
222/222b Tank	12 428932	3904850	2	12 - 18	2.8 - 3.6	23	Ef, Lc, Ma, Me, Mo, Mt, Mv
Line Tank	12 434771	3900009	2	12 - 18	3.8 - 4	78	Ef, Lc, Ma, Me, Mo, Mt, Mv
Camp 2 Tank	12 424630	3901505	2	12 - 18	2.6 - 3.3	51	Ef, Lc, Ln, Ma, Mca, Mci, Me, Mo, Mv, Tb
Pearson Springs	12 426600	3904120	2	12 - 18	3.7 - 3.8	83	Ef, Mci, Me, Mo, Mt, Mv, My, Tb
518c Tank	12 432489	3900064	2	12 - 18	2.6 - 3.8	17	Ef, Lc, Ln, Mci, Me, Mo, Mt, Mv
9011K Tank	12 431940	3897239	2	12 - 18	2.9 - 3.3	37	Ef, Me, Mo, Mt, Mv
Drowned Timber	12 424543	3903604	2	12 - 18	2.7 - 3.3	31	Ef, Lc, Ln, Me, Mo, Mv, Tb
9007P Tank	12 430445	3901370	1	12 - 18	3.3	38	Ef, Ln, Me, Mo, Mt, Mv, Tb
Telephone Tank	12 429745	3898331	1	12 - 18	2.5	5	Mo, Mt, Mv

Table 2. Decay classification system used to categorize Gambel oak (*Quercus gambelii*) bat roost, random, and potential roost trees in northern Arizona, 1999 and 2000.

Decay class	Description
1	Live and healthy
2	Live, declining (dead top branches, dead side branches).
3	Dead with top and most of all limbs intact, tight bark, base solid
4	Dead with broken top and/or missing limbs, most bark tight, base solid
5	Dead with broken top, most of limbs missing, loose bark, >50% bark remaining, some decay at base
6	Dead with broken top, most limbs missing, few stubs present, loose bark, < 50% bark remaining, sapwood decay
7	Little or no bark remaining, advanced sapwood decay, few/no stubs present

Table 3. Decay classification system used to categorize ponderosa pine (*Pinus ponderosa*) bat roost, random, and available trees in 1999 and 2000. Modified from Brigham et al. 1997.

Decay class	Description
1	Live, healthy; no decay; no obvious defects
2	Live, usually unhealthy; obvious defects such as broken top, cracks, or hollows present
3	Recently dead; dead needles still present, little decay; heartwood hard
4	Dead; no needles and few twigs present; top often broken; <50% of branches lost; bark loose; heartwood hard; sapwood spongy
5	Dead; most branches and bark lost; top broken; heartwood spongy; sapwood soft
6	Dead; no branches or bark; broken off along mid-trunk; sapwood sloughing from upper bole; heartwood soft
7	Dead; stubs >3 m in height; heartwood soft; extensive internal decay; outer shell may be hard
8	Dead; stubs <3 m in height; heartwood soft; extensive internal decay; outer shell may be soft
9	Debris; downed stubs or stumps; extensive decay

Table 4. Mist net bat captures for ponderosa pine and ponderosa pine-Gambel oak forests in northern Arizona, 1999. Bat captures were weighed using net effort. Net effort equals hours spent netting in one habitat x area of net (m^2) used in that habitat)/100. Percent capture was calculated for each species by dividing the number of bats of that species captured in one habitat type (pine or pine-oak) by the total number of captures of that species. Weighed capture numbers were used to calculate percentages.

	Ponderosa pine		Ponderosa pine-Gambel oak				
Species	Number captured	(Number captured/ net effort) X 100	Number captured	(Number captured/ net effort) X 100	(Total Number captured/ net effort) X 100	Percent captured in Pine	Percent captured in pine-oak
Antrozous pallidus	0	0	19	1.6	1.6	0	100
Eptesicus fuscus	109	9.3	71	6	15.3	61	39
Idionycteris phyllotis [a]	0	0	4	.3	.3	0	100
Lasiurus cinereus	11	.9	4	.3	1.3	73	27
Lasionycteris noctivagans	6	.5	32	2.7	3.2	16	84
Myotis auriculus	9	.8	46	3.9	4.6	16	84
Myotis californicus [a]	3	.3	1	.1	.3	75	25
Myotis ciliolabrum [a]	5	.4	5	.4	.8	50	50
Myotis evotis	84	7.1	81	6.8	14	51	49
Myotis occultus	71	6	90	7.6	13.6	44	56
Myotis thysanodes	37	3.1	37	1.6	4.7	66	34
Myotis volans	73	6.2	16	1.3	7.6	82	18
Myotis yumanensis [a]	1	.1	2	.2	.3	34	66
Tadarida brasiliensis	20	1.7	4	.3	2	83	17

[a] Insufficient sample size to be considered in comparison.

Table 5: Means, Standard error of the mean, and ranges of Gambel oak trees and microhabitats characteristics used by southwestern myotis (Myotis auriculus) as maternity roosts compared to randomly selected Gambel oak trees and microhabitat sites in northern Arizona, 1999 and 2000. Tree species abbreviations Gambel oak = QUGA, ponderosa pine = PIPO, potential roost Gambel oak tree (≥26 cm drc) = PTQ.

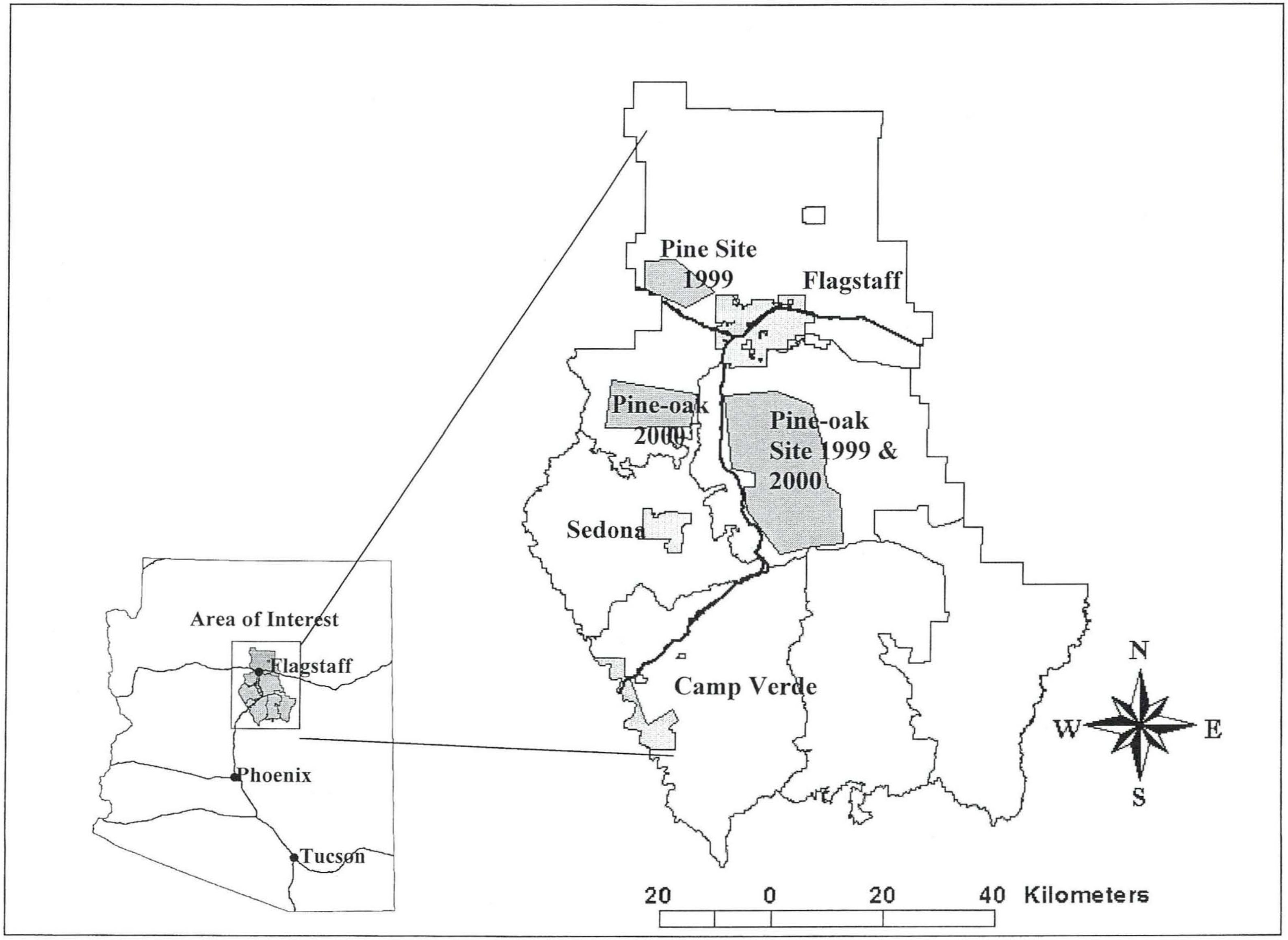
	Roost			Random		
Characteristics	**Mean**	**Standard Error**	**Range**	**Mean**	**Standard Error**	**Range**
Individual Tree						
Diameter at root collar (cm)	46.4	2.0	26.2 - 70.0	43.6	2.6	26.9 - 85.5
Height (m)	10.7	0.6	5.9 - 18.0	8.2	0.6	3.1 - 19.0
Bark remaining (%)	96.2	0.9	80.0 - 100.0	93.0	1.0	70.0 - 100.0
Decay Class (ranking)	2	0	2 - 4	2	0	2 - 5
Microhabitat						
Slope (%)	10.0	2.0	2.0 - 25.0	5.0	1.0	0.0 - 17.0
Aspect (degrees)	217	13	6 - 352	192	15	15 - 354
PIPO/ha	450.6	38.9	180.0 - 1110.0	457.2	69.7	40.0 - 1760
QUGA/ha	303.8	36.9	60.0 - 900.0	289.7	42.5	50.0 - 1160.0
PTQ/ha	81.1	8.9	4 - 230	47.5	4.5	10.0 - 100.0
Basal Area PIPO (m^2/ha)	24.6	1.7	5.0 - 42.0	21.1	2.2	2.0 - 63
Basal Area QUGA (m^2/ha)	13.8	1.4	2.0 - 42.0	9.6	1.0	2.0 - 33.0

Table 6. Results of 4 a-priori models using logistic regression to distinguish differences between *Myotis auriculus* maternity roosts and randomly selected potential roost trees located in 1999 and 2000. Sample size, n, is the number of roost and random trees. k = the number of parameters used in the models. AIC = -2 Log Likelihood x 2k. Δ AIC is a ranking based on subtracting the lowest AIC value from each of the other AIC values.

Model 1: Height of tree + Potential roost Gambel oak trees/ha + constant
Model 2: Potential roost Gambel oak trees /ha + constant
Model 3: Diameter of focal tree + Potential roost Gambel oak trees /ha + constant
Model 4: Potential roost Gambel oak trees /ha + Basal area of oak + constant

Model Number	**n**	**-2 Log Likelihood**	**k**	**AIC**	**Δ AIC**	**Logistic regression total % correct**	**Bootstrap total % correct**
1	64	69.107	3	75.107	0	71.9	68.8
2	64	77.292	2	81.292	6.185	64.1	60.9
3	64	75.357	3	81.357	6.25	67.2	65.6
4	64	76.755	3	82.755	7.648	67.2	65.6

Figure 1. Study area map showing the locations of the Pine Sites and Pine-Oak Sites used to mist net bats, survey echolocation calls, and locate *Myotis auriculus* roosts in northern Arizona during 1999 and 2000.



Pine Site 1999
Flagstaff
Pine-oak 2000
Pine-oak Site 1999 & 2000
Sedona
Camp Verde
Area of Interest
Flagstaff
Phoenix
Tucson
N
W
E
S
20 0 20 40 Kilometers